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An Assessment of the Challenges Associated with Individual Battlefield Power: Addressing the Power Budget Burdens of the Warfighter and Squad

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About This Publication

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Acknowledgments

The research team is indebted to the stakeholders across the Department of Defense who shared their candid insights on the subject of Individual Battlefield Power. We also wish to thank our colleagues in the Joint Advanced Warfighting Division for their contributions to this effort and to our two reviewers, Drs. Michael Fitzsimmons and William J. Hurley.

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Executive Summary

When it comes to having sufficient electrical power for the equipment carried into combat, the dismounted warfighter is the most disadvantaged person on the battlefield.[1] This is largely due to the dismounted warfighter having to carry, on their person, all their equipment and the means to power that equipment. With un-resupplied missions potentially lasting for 72 hours, carried loads can exceed 120 pounds per person. New capabilities and new generations of equipment for both the dismounted warfighter and the small units within which they operate tend to add to, rather than replace or decrease, power requirements. As carried loads near the limits of human capacities, the trends in increasing power requirements are unsustainable.

Given the size of its dismounted force as compared to the other Services, the U.S. Army faces the broadest challenges in developing, fielding, and sustaining powered equipment and power supplies. Army policy sets the squad apart as the decisive unit of dismounted force and the relevant unit of battlefield power analysis. The principal challenge, therefore, is to reduce power demanded by carried equipment while preserving, and someday improving, warfighter and squad capabilities to sense, shoot, move, and communicate.

The Assistant Secretary of Defense (ASD) for Operational Energy Plans and Programs (OEPP) asked the Institute for Defense Analyses (IDA) to examine the key challenges and enablers to the battlefield power budget of the dismounted warfighter over the next five years.[2] The IDA research team conducted a literature review, focusing particularly on Service requirements documents that set, or expand, the boundaries of warfighter future power budgets. This was followed by interviews with officials in requirements, acquisition, and science and technology communities across the Services and at US Special Operations Command. The research results were compiled into a briefing given to ASD(OEPP) and the stakeholder community. The body of this document is an annotated version of that briefing.

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1 Dismounted warfighters operate on foot away from their vehicles or supporting bases for extended periods.

2 Power budget refers to power supplied (typically from batteries); power produced (such as from solar panels); and power required (e.g., radios, optics) in a given mission scenario (e.g., squad movement to contact, 72 hours without resupply). For this research, power was measured in watt-hours.

Each dismounted operation is unique, shaped by factors including mission, enemy, and terrain. This research thus delves into an inherently variable problem space but without a power budget baseline or a common vision for what that baseline should be, and a dearth of power-demand data. Requirements and acquisition stakeholders are scattered across Service and Joint enterprises, thereby complicating efforts to approach power budgets as a squad-level or Soldier-level systems engineering challenge. Individual, rather than integrated, solutions to capabilities gaps predominate and lead to increases in the number, type, and total weight of total batteries carried by the dismounted warfighter.

Some progress is being made in certain areas such as power management where the dismounted warfighter can monitor, and eventually control, power used by radios and sensors. New kit now includes, for example, conformal batteries capable of powering multiple devices at the same time, reducing the number and types of batteries a warfighter must carry. These are necessary but still insufficient steps toward reducing power demands while preserving capabilities. The IDA team recommends the following additional steps:

- Support efforts to measure more fully the actual power demand across a range of missions and conditions.
- Establish ceilings for maximum power available per dismounted Soldier in order to curb ever-increasing appetites for carried-power. All powered equipment must operate within this ceiling for a given mission.
- Elevate system-wide challenges to senior stakeholders:
  – Establish an executive agent for battlefield power. Given its mission to develop, acquire, field and sustain integrated equipment for the Soldier, the U.S. Army's Program Executive Office (PEO) Soldier is a logical choice.
  – Charter the extant Joint Warfighter Power Working Group (JWPWG) as a standing task group, responsive to PEO Soldier. JWPWG will serve to identify power budget issues for consideration by the Defense Operational Energy Board. Service acquisition and requirements stakeholders should participate in JWPWG.
- Leverage the Soldier and Small Unit Power (SSUP)[3] program:
  – Assess the cognitive burden placed on the warfighter power budget.
  – Establish an SSUP Advisory Council of senior enlisted personnel who would collaborate with the SSUP program.

[3] OEPP funds the SSUP program. The U.S. Army Natick Soldier Research and Development Engineering Center leads a multi-year effort to reduce the number, resupply, type, and weight of batteries borne by troops.

- Obviate some power budget challenges with innovations in resupply delivery. For example, despite a broadly accepted requirement to operate dismounted for 72 hours without resupply, many missions require resupply of water (or ammunition).
- Continue Service efforts on power interoperability. Commendable efforts to date have occurred between the U.S. Army and U.S. Marine Corps. Encourage and continue efforts to standardize cable connectors and power management devices. Where possible, a common solution to a common problem should be pursued.
- Encourage continued outreach to the interagency, allies, and partners.

Many of these recommendations challenge organizational processes regarding requirements development and acquisition programming. Senior leadership must engage to effect lasting changes that reverse the unsustainable trends in dismounted warfighter power and weight, and begin to address the problem in a systemic manner.

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Slide 1

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Prepared for
The Assistant Secretary of Defense for Operational Energy Plans and Programs
Project Description AQ-8-3637

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Overview

Slide 3. Objective and Specified Tasks

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Objective and Specified Tasks

Identify the most significant challenges and enablers to the individual and squad-level Joint Warfighter's power budget over the next five years

- Identify
  - Service requirements, objectives, and metrics
  - Key materiel and non-materiel initiatives
  - Energy-related capability tradeoffs
- Address trends & make recommendations on
  - Relative importance of requirements
  - Energy technologies
  - Non-materiel approaches
  - System interoperability priorities
  - Metrics to help prioritize tradeoffs

Slide 4. A Note on Terminology

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A Note on Terminology

- Assigned focus of research was individual battlefield power (IBP)
- While the term IBP is retained within this report, we believe more apt terms are *dismounted warfighter power* and *dismounted squad power*
  - Dismounted warfighters are the most disadvantaged in terms of power budget and weight carried
  - Dismounted warfighters operate within squads
  - Army policy sets the squad apart as the decisive unit of dismounted force and the relevant unit of battlefield power analysis
  - *Warfighter* is preferred over *Soldier* to allow for consideration of Marine Corps, Special Operations, and other dismounted ground forces who face power budget challenges
  - However, the Army faces significant challenges in fielding and sustaining capabilities due to the size and scope of its dismounted force. ***Thus the focus of this assessment is principally on the Army***

Slide 5. The Challenge and Costs

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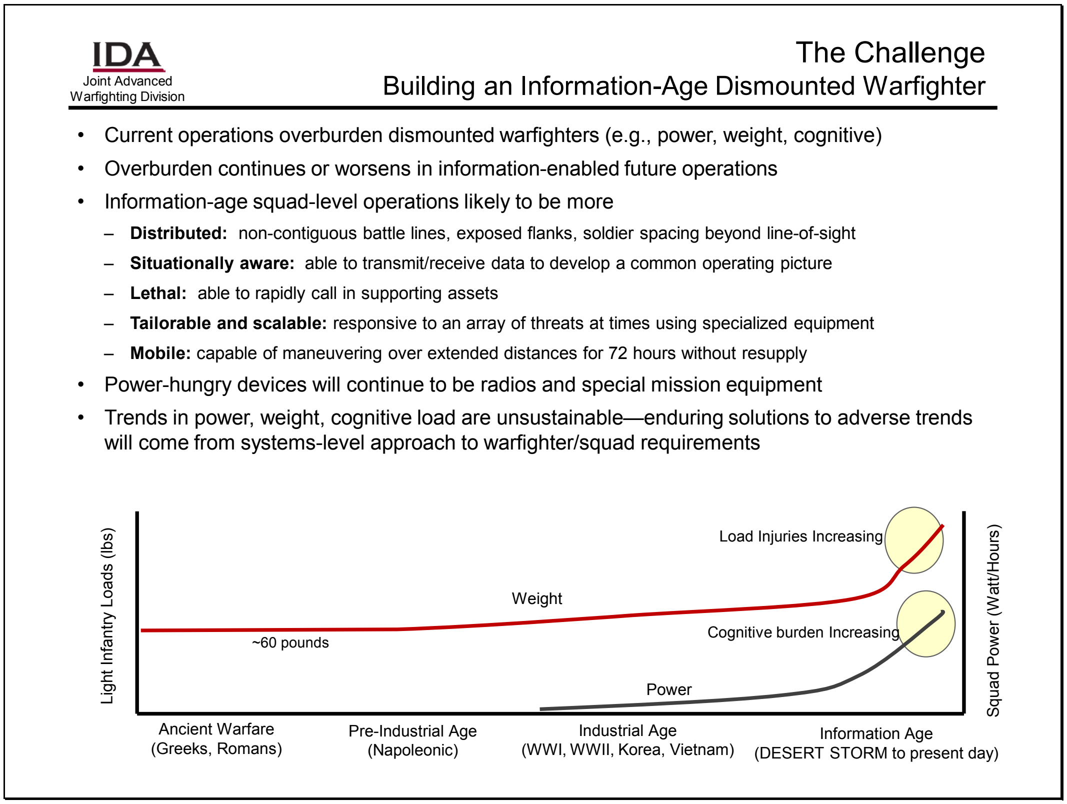
The Challenge and Costs

Slide 6



In general, the loads carried into battle by light infantry remained flat for centuries but began to increase significantly in the last 60 years, particularly in the last decade. An early driver of these increases was the introduction of firearms and their ammunition, but in the Post-Industrial Age various power-consuming electronic devices and the return of body armor have been key drivers. The trend in these increases is unsustainable as loads have already reached the point of reducing mobility and generating substantial rates of physical injury.

FURTHER READING:

For an excellent review of the systems engineering challenges and successes, see “Realizing the Vision: The Soldier/Squad System” by Maren Leed and Ariel Robinson of the Center for Strategic and International Studies, April 2014. Also see “Soldier Systems: Outfitting the Army,” by US Army Brigadier General (retired) James R. Moran, *Army Magazine*, June 2013, pages 19–22.

Slide 7

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Dismounted Warfighter Power Cost in Context

- Power often is lost in the noise from other higher-profile energy topics
  - Expense and difficulties in moving fuel to forward bases
  - Fuel cost for training with platforms or challenges of supplying fuel during operations
  - Soldier systems spending in FY09: 1.5% of overall Army budget
- But the substantial impact of IBP can be measured
  - Army analysis of its Small Unit Power (SUP) initiative estimated spending $653 million over 20 years (procurement + sustainment) would save the Army $1.49 billion in batteries over that same period
  - From 2001 to 2010 the proportion of deployed service members with back problems increased from 1.5 service members out of 1,000 to 28.8 out of 1,000
  - From 2002 to 2011 the VA treated 685,000 Iraq and Afghanistan vets and 55% of the total (377,000) were diagnosed with musculoskeletal injuries (2010 cost was $1.81 billion)
  - IBP is but one component of the overloaded warfighter. If total musculoskeletal injuries could be reduced by just 10%, the estimated savings in healthcare costs would range from $2.2 billion to $3.0 billion over 20 years (CBO cost estimates for 2001–2020)

Because the direct expenses associated with IBP are small, IBP often received less attention than other areas of operational energy such as fuel costs for forward bases or platform fuel use. But when viewed in a wider scope of battery costs and healthcare costs from excessive soldier loads, the IBP cost implications become much more significant and are measured in the billions of dollars.

SOURCES:

Army budget data: Robert B. Brown, MG, Commander, U.S. Army Maneuver Center of Excellence, “The Infantry Squad: Decisive Force Now and in the Future,” *Military Review*, Nov–Dec 2011, p. 7.

SUP cost estimates and healthcare data: U.S. Army Maneuver Center of Excellence, “Overburdened Soldier Load Technology Enabled Capability Demonstration (TECD) 2a Baseline, Version 1,” (Fort Benning, GA: September 26, 2012).

Slide 8. Requirements and Metrics

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Requirements and Metrics

Slide 9

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IBP Requirements & Metrics

- Joint requirements do not exist, nor does a standard baseline
- Common themes in Ground Service requirements (rough priority)
  - Simple, easy to operate, minimal training required
  - 72 hours without resupply across multiple mission types
  - More maneuverable, decreased warfighter load (physical and cognitive)
    - Reduce the number and types of batteries
  - Be able to monitor and manage available energy across the squad
- Appears to be no binding overall weight or power demand limits
- Most common metrics relate to weight reduction (e.g., fewer batteries carried) and form and fit
- Examples of other existing metrics
  - Performance of specific combat tasks
  - Number of carried systems that require a unique battery type
  - Numbers of batteries (by type) carried on some missions

The Institute for Defense Analyses (IDA) research team was asked to identify requirements and metrics across the Services. IBP requirements have been developed at the Service level. While these requirements do not exist at the Joint level, and given the variances in Service mission sets, it is unlikely that Joint requirements would measurably contribute to addressing the IBP challenges. The most clearly defined requirements exist in the Army and Marine Corps, both of which have conducted capabilities-based assessments at the squad level and have identified needs in capabilities documents. Requirements for the Air Force and Special Operations Forces are less clear, as are any requirements for the Navy beyond those established for the Marine Corps.

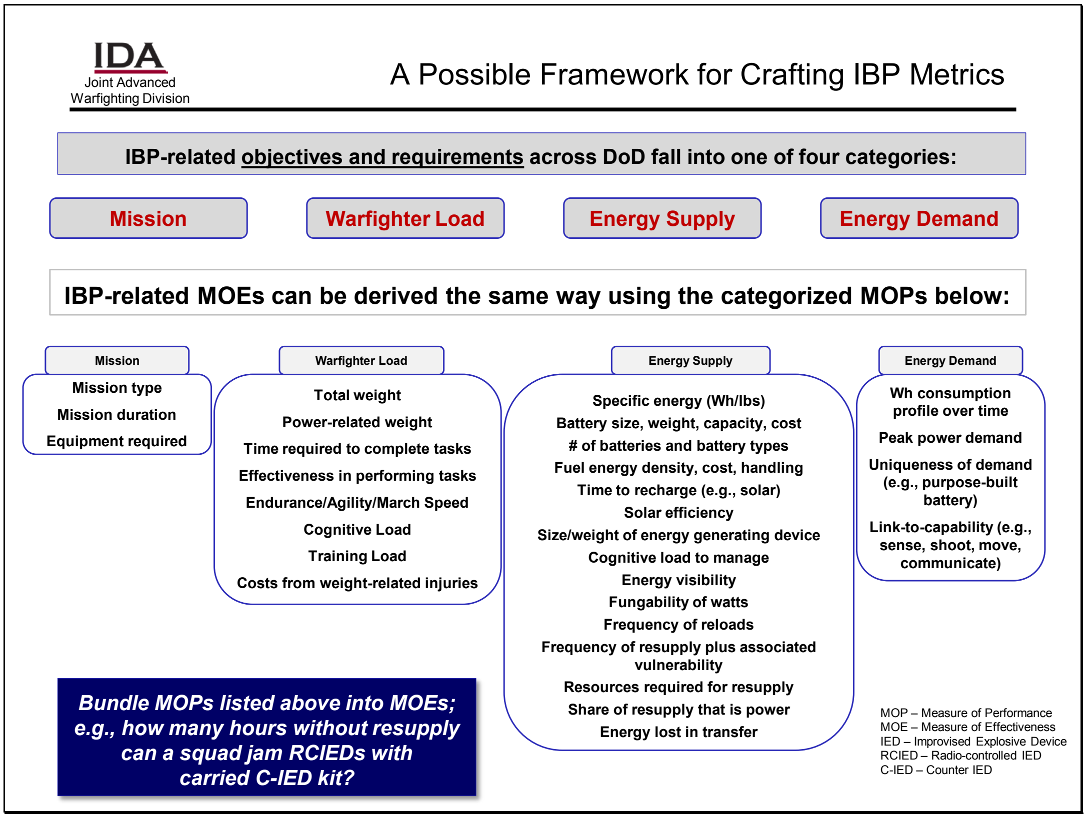
In the case of the Army and the Marine Corps, their overall IBP-related requirements generally align as listed in the slide above. This has allowed a good degree of grassroots coordination and cooperation in research, development, and acquisition, although both Services generally are pursuing their own material solutions. Where they have been able to cooperate is in the conformal battery used in the power management systems under development by both Services. The battery was originally designed for the Army's power management system, but then was modified by the Army to better match Marine Corps specifications.

(Continued)

(Slide 9 continued)

The most common metric for measuring improvement is generally *weight reduction through fewer carried batteries and/or fewer battery types*, although both the Marine Corps and Army look at additional factors such as *form and fit* when assessing possible solutions. The Marine Corps specifically targets *mobility* as a metric, which is a combination of weight, bulk, and stiffness. Other metrics encountered include the examples listed on the slide (no. 9).

Slide 10



This slide presents some initial thinking from the IDA research team on both IBP metrics and a structure for organizing those metrics. The team found that the IBP-related objectives and requirements found could be organized into four categories: *mission*, *warfighter load*, *energy supply*, and *energy demand*. A natural linkage exists between metrics and objectives/requirements; such a four-category scheme would also work just as well for metrics.

The metrics shown here in the four categories should be considered *representative*, and not a comprehensive list. This list should be useful for any future metrics development effort, in part by illuminating the kinds of information that would be needed to measure satisfaction of various requirements or objectives. Many of the metrics listed here are highly detailed and would be *measures of performance* (MOPs). A bundling of these and other metrics would lead toward *measures of effectiveness* (MOEs).

Slide 11. Trends and Tradeoffs

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Trends and Tradeoffs

Slide 12

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Notable IBP-Related Trends

Overall Load

- Since 2003, the average Soldier loads have increased 21% since 2003

Power Supply and Power Management

- 2010: First time majority of Army batteries purchased were rechargeable
- For the near- to mid-term, batteries will be the main source of carried power
- Power management systems central to both Army and USMC IBP efforts
  - Harvesting and scavenging integrated, helps mitigate battery proliferation problem
  - Training load and cognitive load impacts less clear
- Mission-specific equipment brings increased power demand burdens
  - For example, adding C-IED equipment to a 72-hour mission can increase total power-related weight carried by the squad by 21% (or an additional 25 lbs.), not counting the weight of the C-IED gear itself

Science and Technology (S&T) Focus

- Much effort within the S&T community is oriented on increasing power supply
- Some emerging efforts include a focus on reducing power demand

Warfighter burdens increasing, quantum leaps in power demands, solutions oriented on power supply

According to the U.S. Army's Maneuver Center of Excellence (MCoE), in 2013, the average soldier load source increased from 101 lbs. to 122 lbs. (U.S. Army, MCoE, *Capability Development Document for Small Unit Power, Increment 1*, 3 April 2013, p. 3.) For the 2012 load study baseline, see U.S. Army Maneuver Center of Excellence, "Overburdened Soldier Load Technology Enabled Capability Demonstration (TECD) 2a Baseline, Version 1," (Fort Benning, GA: September 26, 2012).

Army battery purchases: Eric Beidel, "Soldier Energy Needs Outpacing Technology, Policy," *National Defense*, March 2012, p. 2.

Army S&T trend: IDA team member, telephone interview with senior leader in an Army S&T Organization, 18 June 2013.

Counter-Improvised Explosive Device (C-IED) data are drawn from a comparison of two 72-hour missions (U.S. Army Maneuver Center of Excellence, "Overburdened Soldier Load Technology Enabled Capability Demonstration (TECD) 2a Baseline, Version 1," (Fort Benning, GA: September 26, 2012).

(Continued)

(Slide 12 continued)

The Enter and Clear Mission did not include any C-IED equipment for the squad; but the Movement to Contact Mission did (THOR III, Goldie, Minehound). Batteries resident in each system were counted along with the 8x BA-5590 batteries carried as spares.

One device (Homeland Security, Biometric Identification, and Personal Detection Ethics (HIDES) biometric device) was listed in the Enter and Clear Mission but not in Movement to Contact Mission; the battery weight for that device was factored in (with +21% weight gain as a net change).

Total squad power-related weight for Enter and Clear was 120.1 lbs. for the squad; and for Movement to Contact it was 145.4 lbs. (U.S. Army Maneuver Center of Excellence, "Overburdened Soldier Load Technology Enabled Capability Demonstration (TECD) 2a Baseline, Version 1," (Fort Benning, GA: September 26, 2012.)

Slide 13

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Example of a Capability* Tradeoff

- As some capabilities have been added or improved with a new kit, that kit has driven up the overall weight, which trades off other capabilities
- Most notable capability loss is “move” (e.g., mobility, range, endurance)
- As new equipment is added, this trend will continue
- FM 21-18, *Foot Marches,* describes the tradeoffs for every 10 lbs of load added beyond 40 lbs
  - March distance per 6 hrs decreases by 2 km
  - Assault course time increases by 15%
- Personnel marching at 3 kph with 40 lbs reach exhaustion level at the same time that other personnel marching 2 kph with 120 lbs (at 9 hours) reach the same level of exhaustion

* In this analysis, squad capability = sense, shoot, move, and communicate.

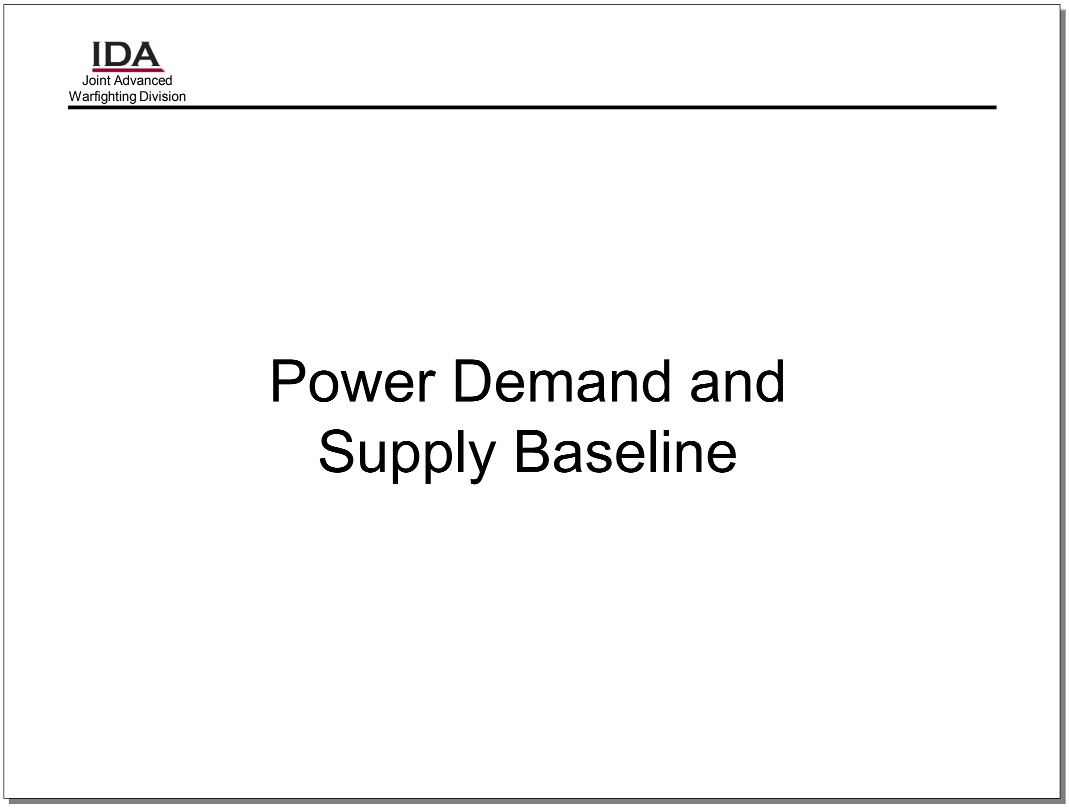
A comment sometimes heard by the IDA research team was that weight reductions were desirable—but not if it meant losing any capabilities. But such comments overlook the fact that some capabilities were previously traded off as weight was added to warfighters (namely, the *mobility* and *endurance* capabilities).

Much like the design paradigm for armored vehicles (where mobility, protection, and lethality are traded off against each other in the design process), dismounted warfighters who carry additional weight are trading off mobility for something else. That tradeoff may be a net advantage but awareness should be maintained of that trade space.

SOURCES:

Field Manual 21-18, *Foot Marches*, Department of the Army (Washington, DC: June 1990) (100, p. 5-5).

Slide 14. Power Demand and Supply Baseline



Slide 15

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Challenge of Mapping the IBP Baseline

- A power demand baseline does not exist
  - Power demand: Power consumed by a device across a range of conditions, missions, mission durations, and duty positions
- Best available data is a baseline of overall Army Soldier loads, from which a power supply baseline could be derived
  - Primary source: Army's TECD 2a soldier load baseline (2012)
    - Mapped every duty position in an infantry platoon
    - Covered three missions (Move to Contact, Enter and Clear, Cordon and Search) for 18 hours and 72 hours
  - IDA team derived a supply baseline from the TECD 2a
    - Used the equipment listing from TECD 2a and combined with other sources on battery type by device, battery weight, and battery energy capacity
- USMC has extensive data on individual Marine loads from Afghanistan, but the IDA team did not have access to this data
- Detailed data on USAF or SOF loads was not found

Mapping the IBP baseline, in terms of both supply and demand, proved more difficult than expected. Detailed assessments of power supply were available—namely, the Army's TECD 2a study—but no detailed and comprehensive mapping of the power demand was found. The IDA team learned of detailed USMC IBP data late in this project but it was too late to incorporate into the IDA baseline work. The IDA team expects that this data will also be supply focused (e.g., batteries carried).

The TECD 2a study was focused on overall soldier load and did not address many aspects of power. The IDA team was able to use the listing of power-consuming equipment and combined that with other sources to tally overall battery weight and energy capacity.

SOURCES:

U.S. Army Maneuver Center of Excellence. "Overburdened Soldier Load Technology Enabled Capability Demonstration (TECD) 2a Baseline, Version 1," (Fort Benning, GA: September 26, 2012).

Slide 16

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Sample of Army TECD 2a Database

- TECD 2a database addresses load in three layers
  - Common equipment carried by all
  - Duty-specific equipment
  - Mission-specific equipment
- Table depicts
  - Squad leader, 72-hour mission
  - Common equipment total weight
  - Duty-specific equipment breakout
  - Not shown – mission-specific equipment

72-Hour Mission, Squad Leader			
Item	**Qty**	**Lbs**	**Total (lbs)**
Common Equipment			107.49
Squad-Leader Equipment			
M4 (Rail system, sling, BUIS, collapsible butt-stock)	1	7.50	7.50
Magazines with 30 rounds each	7	1.30	9.10
M150 RCO (ACOG)	1	1.10	1.10
Weapon Light w/battery	1	0.65	0.65
AN/PEQ-15 w/battery	1	0.49	0.49
PVS-20 (ENVG) w/battery pack	1	1.98	1.98
MOLLE Rifleman Kit Pouches (Grenade pouch x2 / Double Mag Pouch x3, utility pouch x2)	1	1.66	1.66
M67 Frag Grenade	2	0.93	1.86
M83 Smoke Grenade	2	1.00	2.00
Nett Warrior EUD w/cable (See Below)	1	2.00	2.00
SWIPES (charging cup, radio pouch, side adapter, battery cable)	1	0.50	0.50
SWIPES conformal battery (carried)	1	2.40	2.40
SWIPES conformal battery (extra)	1	2.40	2.40
M24 Binos	1	1.26	1.26
AA batteries	20	0.05	1.00
Compass and map (Set)	1	0.35	0.35
Squad-Leader Equipment Subtotal			36.25
Total of Squad Leader and Common Equipment			143.74

Key Point: TECD 2a includes some equipment yet to be fielded (e.g., Nett Warrior, advanced power management)

In the slide above, the orange-colored cells denote candidates for tactical resupply during the 72-hour mission. Blue cells denote items that might be offloaded to some other cargo-carrying platform (i.e., because they were less likely to be needed quickly by the Soldier), were such a platform available (e.g., an unmanned ground vehicle). Common equipment includes items carried by all Soldiers in the squad and includes items such as uniform, helmet, food, water, gloves, and protective eyewear. The TECD 2A also included the Rifleman Radio in the list of common equipment. Subsequent to the outbrief of this research, the IDA research team learned the Army is reconsidering its decision to issue the Rifleman Radio to every squad member. We understand this decision is a function of cost rather than the performance of the radio itself.

Slide 17

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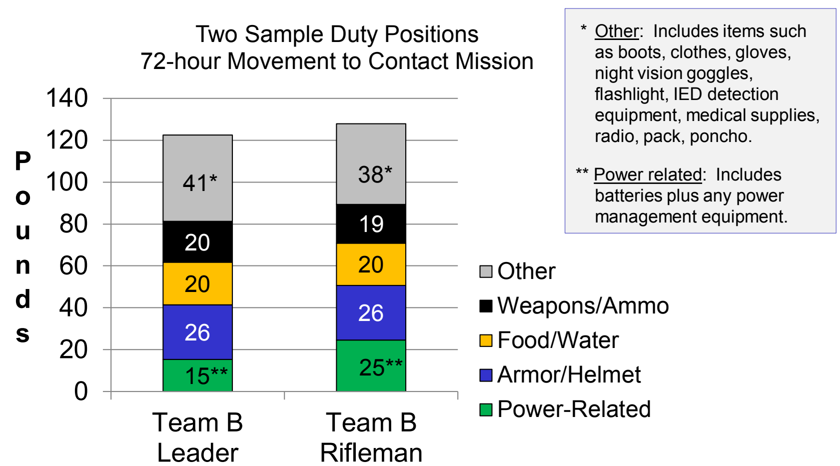
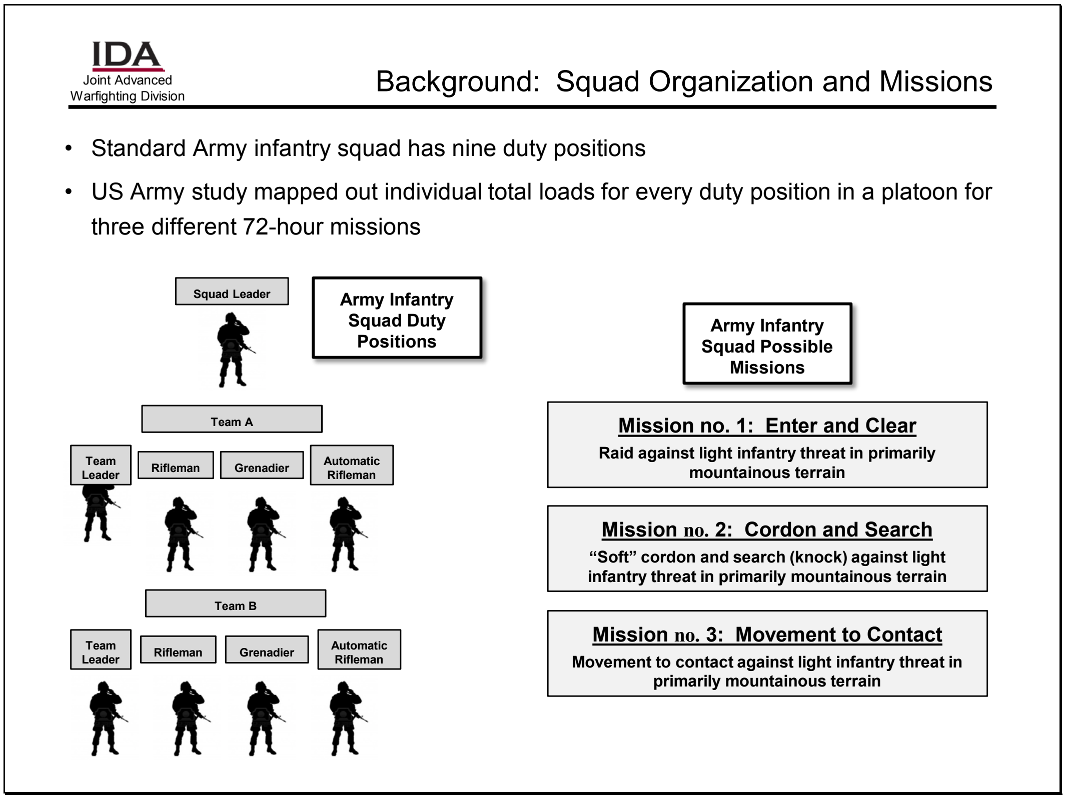
Power-Related Weight vs. Overall Load Carried



- **Power-related weight** is one of many contributors to overloaded warfighters
  - 13% of overall Team B Leader load
  - 19% of overall Team B Rifleman load

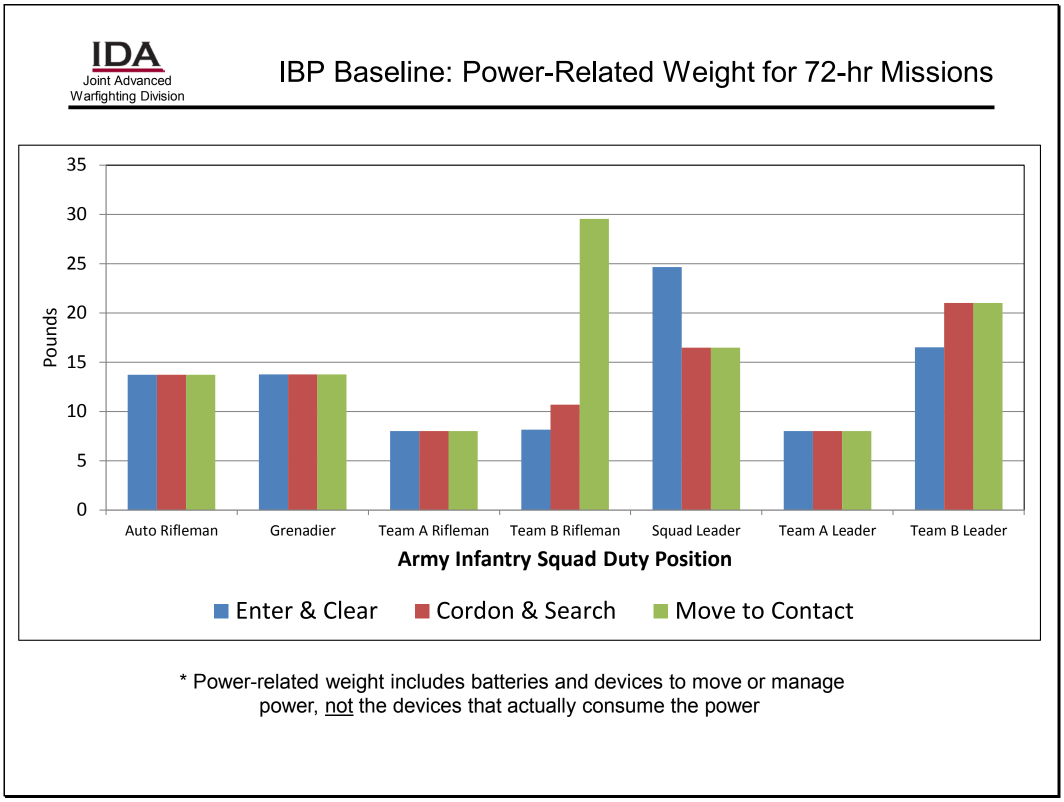
While power-related weight is a significant contributor to the warfighter's overall load, it is generally less than a quarter of the overall weight carried. This highlights the need for a broad weight-reduction effort, encompassing many areas in addition to power-related weight, if significant reductions are to be achieved. In the case of the Team B Leader, even a complete elimination of power-related weight would not reduce his overall load below 100 pounds.

Slide 18



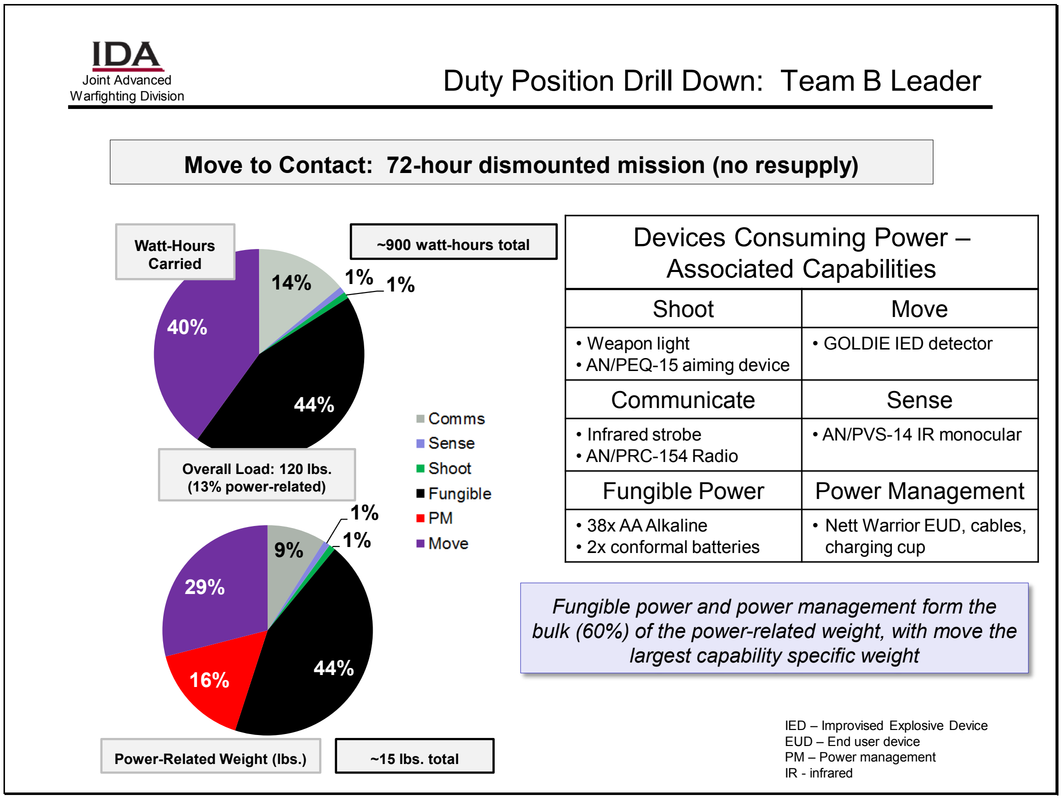
Because the IDA team had better data on Army power supply and power-consuming equipment, the team conducted a drill-down at the infantry squad level. The TECD 2a study mapped the overall load for every duty position in an infantry platoon for three different 72-hour missions, with limited detail on shorter 18-hour versions of each mission. Given the processing needed to convert the TECD 2a overall load data into power supply data, the IDA team chose to to examine he Team B Leader and Team B Rifleman. These representative positions avoid the uniqueness of the squad leader while still exploring leader loads (a team leader) and a member of the squad without specialized weapons (rifleman). Two missions were picked because they represented one mission with C-IED equipment (Move to Contact Mission), and one without (Enter and Clear Mission).

Slide 19



At a reduced level of detail, showing only power-related weight from the TECD 2A data, this graph depicts the weight distribution across each duty position for each of the three missions. For some duty positions (e.g., automatic rifleman, grenadier), there is no variation in power-related weight across the three missions, while for others it can vary greatly (e.g., in the Move to Contact Mission, the power-related weight of Teams A and B Rifleman varies from 8 lbs. to 29 lbs.).

Slide 20

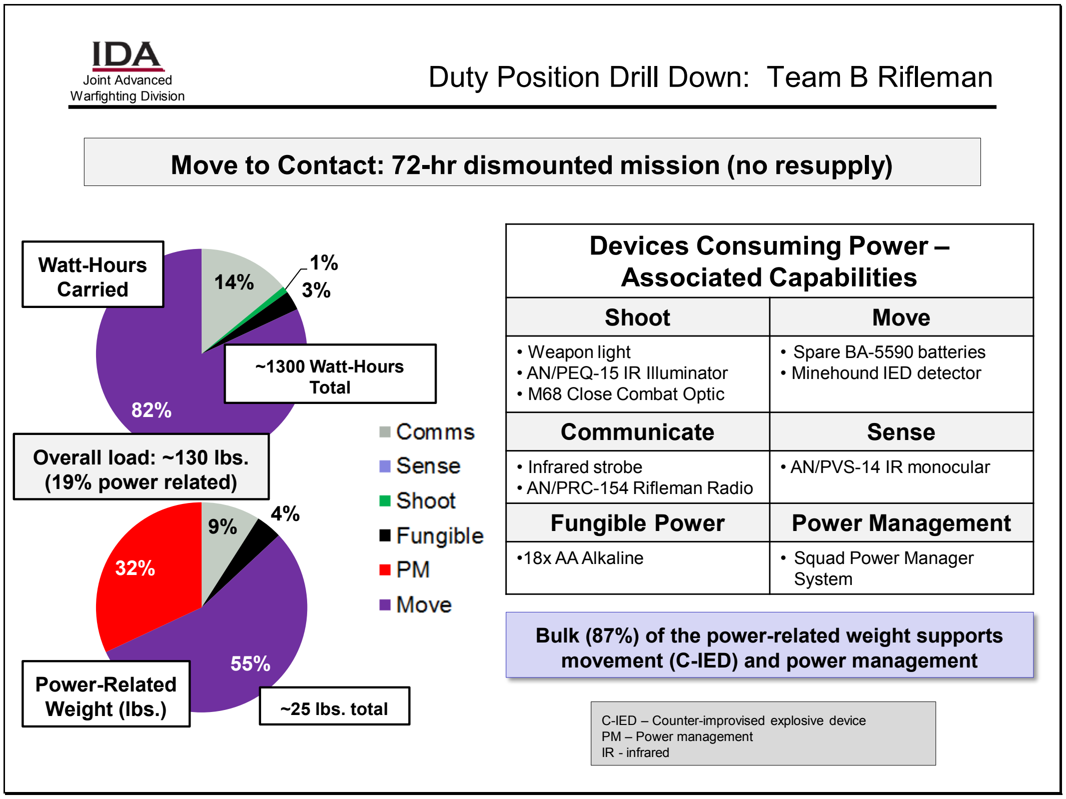


Mapping power needs-to-capabilities helps to identify what capabilities are driving the power and power-related weight levels. This, in turn, makes it easier to see the potential for the largest power savings (e.g., in the areas of counter-improvised explosive device (C-IED) and communications). Because much of the kit associated with these various capabilities comes from different organizations, this mapping provides direction as to which organizations should be engaged in the efforts to reduce demand levels.

In the slide above, the table on the right side lists both devices that consume power and items that supply the power. The pie charts on the left side only factor in the power supply in terms of either watt-hours or weight. The power-consuming devices are mentioned to make clear that the link traces to the actual equipment.

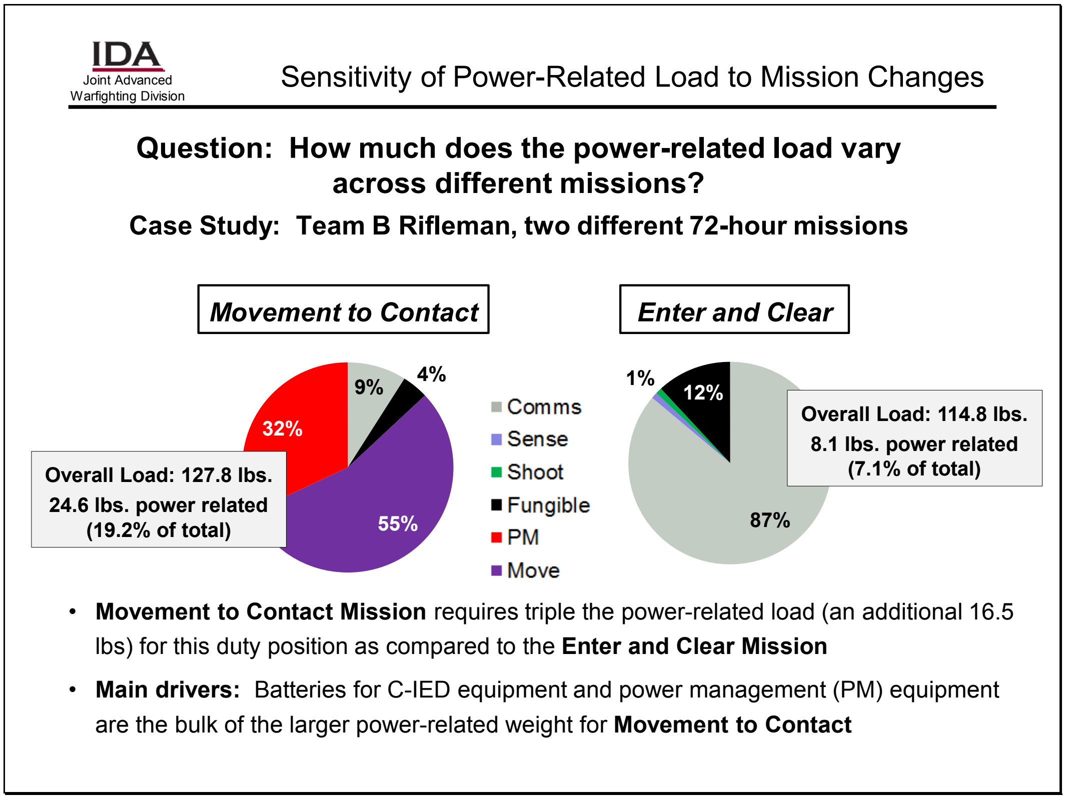
For this duty position and mission, it is clear that the C-IED capabilities carried for this mission generate the largest portion of power-related weight that can be tied to a particular capability. Because of its very nature, the even larger weight in fungible power carried by this duty position cannot be traced to a particular capability. While this power management capability enhances the capability of the warfighter to distribute power where needed, this makes it impossible to track a large portion of the power carried to a specific piece of equipment or capability. That inability to trace supply to specific devices is an argument for better data on what the various devices are consuming, not a simple listing of the batteries carried for them.

Slide 21



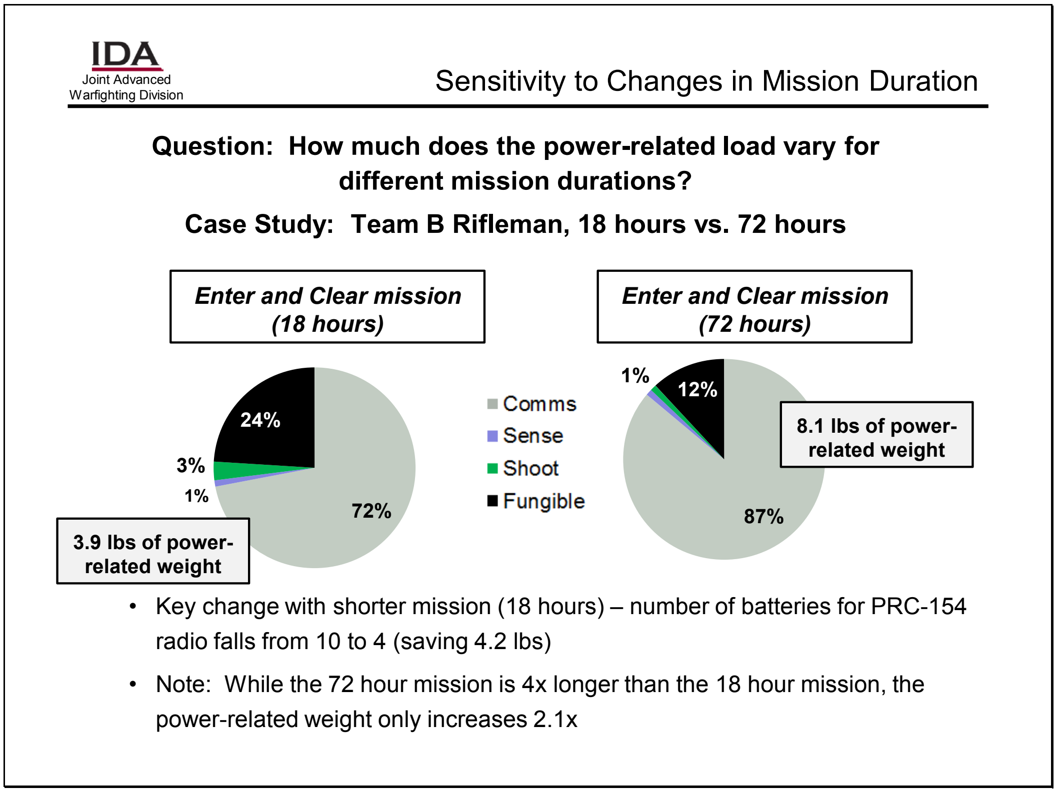
For this duty position, the power-related weight for C-IED dominates. Much of this move-related demand comes from the five spare BA-5590 batteries carried. These batteries weigh a total of 11.25 lbs. and they power the various C-IED devices carried by this Soldier and the rest of squad in this mission. For this particular mission, the Soldier also has to carry the one Squad Power Manager for the squad.

Slide 22



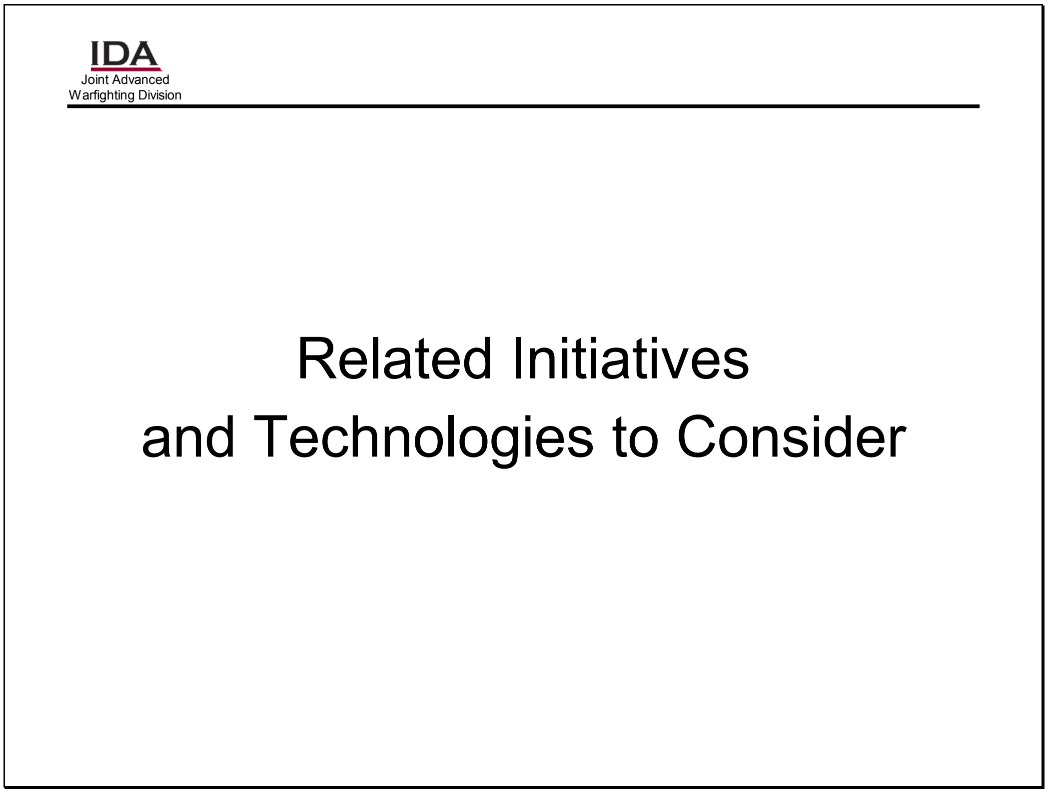
This slide highlights how changes in mission can drive large changes in power-related weight. For the Team B Rifleman, his load for power drops by two-thirds when the mission changes to Enter and Clear, removing 16.5 pounds.

Slide 23

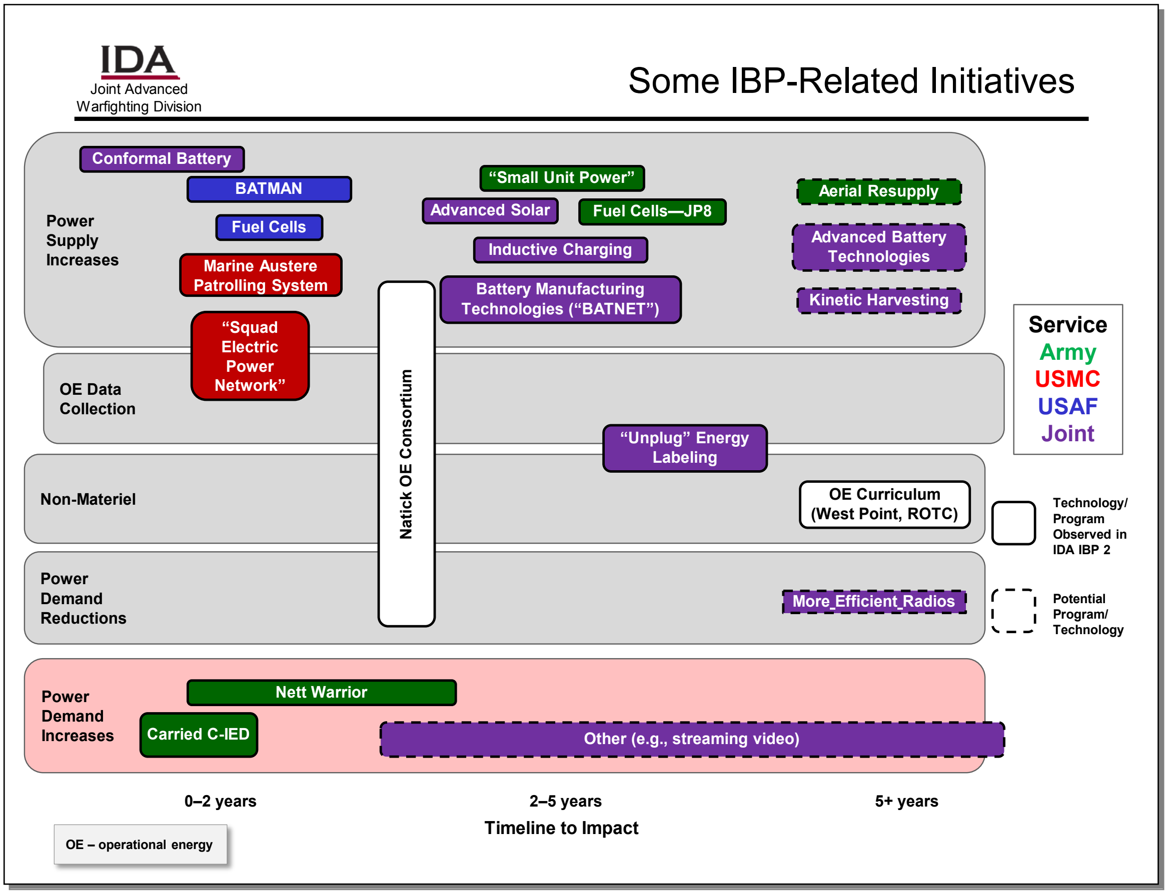


In this slide, the variable is *mission duration*. When the same mission extends from 18 hours to 72 hours, a four-fold increase in duration, the power-related weight carried increases by about half that (2.1 times). This shows a *non-linear relationship between mission duration and power-related weight carried*, and factoring in harvesting and scavenging would further complication that relationship. When adding robust demand data, it would be possible to draw high-resolution power-related weight curves, extending them out beyond 72 hours.

Slide 24. Related Initiatives and Technologies to Consider



Slide 25



The key point from this graphic is the concentration of activities to increase power supply, while relatively few activities are targeted on reducing demand or collecting data. Indeed, some ongoing activities will likely increase power demands.

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Technologies to Consider for Additional DoD Focus (1 of 2)

- Commercial technologies may prove useful with limited DoD investment
- Some less prominent commercial technologies could yield significant benefits with additional DoD attention and investment. For example:
  - **Energy Demand Data Collection** (Status: Pilot-scale field testing underway)
    - Develop and implement **modeling and simulation tools**, and minimally observable embedded sensors within equipment to collect power demand data
    - Challenges: Wide number of contextual variables also required for data collection (e.g., duty position, individual preferences, mission), does not address data storage, analysis needs
    - Metrics addressed: Characterizes link to capability, context-specific technical power specifications
  - **IBP Information Management Tools** (Status: Conceptual)
    - Challenges: Developing representative datasets that incorporate relevant tactical variables, minimizing cognitive load for those at tactical edge
    - Metrics addressed: Reduction in cognitive load~~,~~ enables intuitive demand management
    - Develop planning and analysis tools, and information applications using real-time energy data, baselines, and tactical data to inform energy resource management decisions

(Continued on the next slide)

Because the commercial sector's investments in portable power supply and demand are extensive (driven by a large market for portable electronics), and far larger than DoD's current demand for portable electronics, DoD can derive substantial benefits for modest cost in leveraging commercial technologies.

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Technologies to Consider for Additional DoD Focus (2 of 2)

(Continued from the previous slide)

- E-Textiles (Status: Conceptual)
  - Wearable conductive materials embedded within vest. May allow elimination, reduction of cables currently used to distribute power on soldier, could lead to significant improvements in form/fit
  - Challenges: cost, durability, left/right positioning of equipment on vest, possible signature issues
- Wireless Recharging (i.e., inductive charging) (Status: existing research)
  - Allows for cable-free power transfer between power sources, such as vehicle-soldier charging, or movement of power within the soldier platform (e.g., helmet-torso).
  - Challenges: Long-term planning and engineering required for vehicle and soldier interface compatibility, inductive charging has relatively high power loss
  - Metrics addressed: Frequency of resupply, reduction in management cognitive load, potential to increase energy carried
- Innovative Resupply Methods (Status: Conceptual)
  - Could obviate the need for 72-hour unsupplied solutions, lead to increases in flexibility of power-related weight carried, could lead to increases in power consumption.
  - Challenges: Disposal of spent resources, signature of delivery vehicle
  - Metrics addressed: Introduces high specific energy fuels to the warfighter, generation potential

See next three slides (28–30) for additional information on resupply

Wireless recharging is an area of significant commercial interest, although the conditions under which that recharging would take place have significant differences. For example, commercial interest has been increasing in the recharging of portable electronics at retail locations such as a coffee shop table top. For DoD, the need involves a warfighter's tactical vest while on the move and in all weather conditions.

SOURCE FOR E-TEXTILES:

Advanced Research Projects Agency–Energy (ARPA-E) FOA DE-FOA-0000938, "Personal Thermal Management Systems to Reduce Building Energy Consumption," (Washington, DC: November 13, 2013).

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- As important as any other factor in the power supply–demand equation is the provision of **no power resupply** during a 72-hour mission
  - TRADOC "determined that small units should be capable of operating for 72 hours in austere environments without the need for battery resupply"
- But what if that were not the case?
  - Easy to envision conditions where units would require resupply of ammunition, food, and/or water during a 72-hour mission, so why not add power to that list?
- MCoE TECD 2a referenced "responsive resupply" as one way to reduce the Soldier's burden
  - Identified candidate materials for resupply including ammo, water, food, and batteries
- Resupply options - ground
  - Robotic ground vehicles—more R&D needed before these become useful to small unit operations

MCoE – US Army Maneuver Center of Excellence
TRADOC – US Army Training and Doctrine Command

> The approved Operational Energy for Sustained Ground Operations (OEfSGO) Initial Capabilities Document (ICD) and the Squad as a Foundation of Decisive Force (SFDF) Capabilities Based Assessment (CBA), generated by the United States Army Training and Doctrine Command (TRADOC), have determined that small units should be capable of operating for 72 hours in austere environments without the need for battery resupply. (U.S. Army, Maneuver Center of Excellence, *Capability Development Document for Small Unit Power*, Appendix G, "Operational Mode Summary/Mission Profile, undated, p. 1.)

See also the TECD 2a study (U.S. Army, Maneuver Center of Excellence, Overburdened Soldier Load Technology Enabled Capability Demonstration (TECD) 2a Baseline, Version 1 (Fort Benning, GA: September 26, 2012), pp. 11–32, 35). Additional detail on TECD 2a resupply was provided. The MCoE study identified the following:

- Between 363 lbs. and 388 lbs. in equipment candidates for possible resupply (varied by 72-hour mission).
- Between 14.5% and 18.2% was power related.
- Between 52.5 lbs. and 70.5 lbs. (figures for entire squad) (pp. 11–32).

The 2011 Army experiment: U.S. Army Evaluation Center, "Army Expeditionary Warrior Experiment (AEWE) Spiral G, Initial Insights Briefing," 22 December 2011, pp. 3, 8–9; subject is FOUO.

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The Resupply Option (2 of 3)

- Air delivery more viable in the near- to mid-term
- Operational example – single Army squad (with Nett Warrior) on 72-hour Enter and Clear Mission
  - Carries baseline supply of energy (today this would be 90 lbs. of batteries)
  - Receives one aerial resupply of ~90 lbs. of some from of energy during the mission
    - Ideally, this would be some expendable fuel, perhaps for fuel cells
    - Otherwise it creates the problem of having to fly back out expended batteries (to avoid leaving a signature or materiel useful to the enemy)
    - Squad members could then approximately double their power consumption during that mission
- Key parameters for aerial IBP resupply
  - Accurate, stealthy, responsive, safe for cargo, affordable, safe for personnel

Battery resupply weight was drawn from an Army overall load baseline for the 72-hour Enter and Clear Mission for a complete Army Squad. The 90 pounds include all batteries but not those power-related items that are not consumables such as power management equipment like the Squad Power Manager. (U.S. Army Maneuver Center of Excellence, "Overburdened Soldier Load Technology Enabled Capability Demonstration (TECD) 2a Baseline, Version 1," (Fort Benning, GA: September 26, 2012.)

A key consideration here would be the *form of the power resupplied*. Troops generally do not discard batteries as they would produce a signature that could be used by the enemy to power IEDs (improvised explosive devices). If the resupply of power came in the form of batteries, it would be in addition to the overall weight carried by the squad, in large part defeating the purpose of the resupply. For resupply to be a true advance in capability, the power delivered needs to be a consumable, such as JP8, a type of jet propulsion fuel, in a disposable or collapsible container. USAF personnel currently use fuel cells to produce power, but these fuel cells require specialty fuels that the Army is reluctant to introduce into its supply chain. Given the far larger problem the Army is trying to solve (achieving standard issue power for infantry units), this reluctance seems reasonable. The Army would rather field fuel cells that use the JP8, the standard battlefield fuel, but the fuel cell technology needs more development for JP8 fuel cells small enough to be man-portable and suitable for patrols.

(Continued)

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Another resupply parameter is to *the degree it increases the signature of the receiving unit*. How obvious will it be that an American patrol is getting resupplied? How far away will enemy units gain this understanding? How accurately will they be able to locate U.S. personnel?

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The Resupply Option (3 of 3)

- Several commercial technology examples
  - Logistics Gliders LG-1000 disposable GPS-guided glider
    - In development, R&D agreement with Natick Soldier Center
    - Up to 70-mile range, all weather, 1,000 lbs. cargo capacity
    - Twenty-eight can fit in a C-130
    - Cheaper than parafoil nylon (LG-1000 prototype $600), disposable
    - Autonomous guidance, 25-mile accuracy, soft landing via braking parachute

LG-1000

  - Matternet medical resupply drone (small quad-rotor)
    - First testing after Haiti's earthquake (2010)
    - 4.4 lbs. payload delivered over 10 km in 15 minutes
    - Each 10-km flight costs $0.24
    - At known landing locations drone can autoswap cargos and batteries for itself
    - While intended for medical resupply, a 4.4 lbs. payload would be sufficient for 83 AA alkaline batteries (a total of 222 batteries needed for a squad over a 72-hour Enter and Clear Mission)
- How such technologies could be used for resupply would be a rich area for concept development

Sources: LG-1000 image used with permission from Logistics Gliders, March 2012, www.logisticsgliders.com, accessed 1 October 2013. Andreas Raptopoulos, "Speedy Delivery," Presentation at Technology, Entertainment and Design (TED) Global 2013, accessed October 1, 2013, http://blog.ted.com/ 2013/ 06/11/ speedy-delivery-andreas-raptopoulos-at-tedglobal-2013/.

LG-1000: "Logistic Gliders is excited to announce it has fully executed a Collaborative Research And Development Agreement (CRADA) with the Natick Soldier Research, Development and Engineering Center (NSRDEC) in Natick, Massachusetts. CRADAs will allow both parties to collaborate on the planning, execution, and post-processing of data for flight tests of the LG-1000." March 2012, www.logisticsgliders.com, accessed 1 October 2013.

First prototype was built for $600, one-third the cost of the nylon in today's cargo parafoils. LG-100 can also be deployed from larger cargo aircraft or helicopters (http://logisticgliders.com/ news.html, accessed 1 October 2013).

MATTERNET DRONE: Matternet's goal is to build medical resupply networks for remote regions. In the kingdom of Lesotho, which is surrounded by South Africa, creating a drone network serving 47 clinics and 6 labs covering an area of 138 square kilometers would cost less than $1 million. The system includes electric flying vehicles, landing stations, routing software, and an operating system that runs the whole network.

(Continued)

(Slide 30 continued)

Carrying a 2-kilogram payload, Matternet's current model UAVs can cover a 10-kilometer distance in 15 minutes. The drones fly at an altitude of 400 feet, safely out of the way of other aircraft, along preprogrammed routes to known landing stations where they can automatically swap batteries, drop off or pick up a payload, and take off again. Automated route planning helps drones navigate such obstacles as network load and bad weather. (http://blog.ted.com/2013/06/11/speedy-delivery-andreas-raptopoulos-at-tedglobal-2013/, accessed 1 October 2013.)

Battery count information drawn from an Army overall load baseline. (U.S. Army Maneuver Center of Excellence, "Overburdened Soldier Load Technology Enabled Capability Demonstration (TECD) 2a Baseline, Version 1," (Fort Benning, GA: September 26, 2012).

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IBP Demand Baseline – Factors to Consider

- Power demand in each possible mode of operation, time spent in each mode, demand over time
- Effect on demand from a range of conditions, missions, and individual user preferences
- Results would be a range of *probable* consumption levels rather than a precise point prediction
  - Do some devices have a wider variation in demand than others?
- Should include the variability in harvesting and scavenging
- Demand changes overtime in a given conflict
  - Did IBP demand change from 2003 Iraq to 2006 Iraq?
- Collection will be a challenge given number of variables
  - Collection options: data loggers per device, with power management equipment
  - Some initial steps underway to collect consumption data

CERDEC (U.S. Army Communications-Electronics Research, Development and Engineering Center) is interested in collecting data via the Squad Power Manager device while a Marine Corps effort (SEPN, Squad Electric Power Network) has begun using data loggers on some radios used in USMC field exercises.

The ability to track actual power consumption in the field could be useful during a conflict. For example, operations in Iraq in 2003 were very different from those of 2006 and 2007. Data showing an increase of 10% versus an increase of 75% would support different courses of action by organizations procuring or designed power-consuming equipment. Moreover, changes in demand should be assumed, as should the difficulties in adapting to those changes absent consumption data. Even at one given time in a theater, there might be substantial differences in power consumption by dismounted warfighter across a theater. For example, could the Marines in Regional Command–Southwest in Afghanistan have been using much more or much less power than Army Soldiers in Regional Command–East?

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Sample of Questions Demand Data Could Support

- Which devices use the most power and thus offer greater savings potential?
- How may changes in unit organization reduce demand?
- What capabilities are driving the bulk of power demand?
  - May illuminate candidates for moving off warfighters to proximate platforms
- Does a squad in the field have the power remaining to execute another 24 hours of “movement to contact”?
  - If not, how could that squad modify its power demand to make that possible?
- What are the power supply implications of a proposed new piece of equipment?
- How has adaptation in a conflict affected power consumption?

Paradigm shift – Increasingly sophisticated questions about IBP have outpaced the available data; data collection must now catch up

The above questions reflect the diversity of customer requirements for IBP demand data, which are explored in more detail on the next slide.

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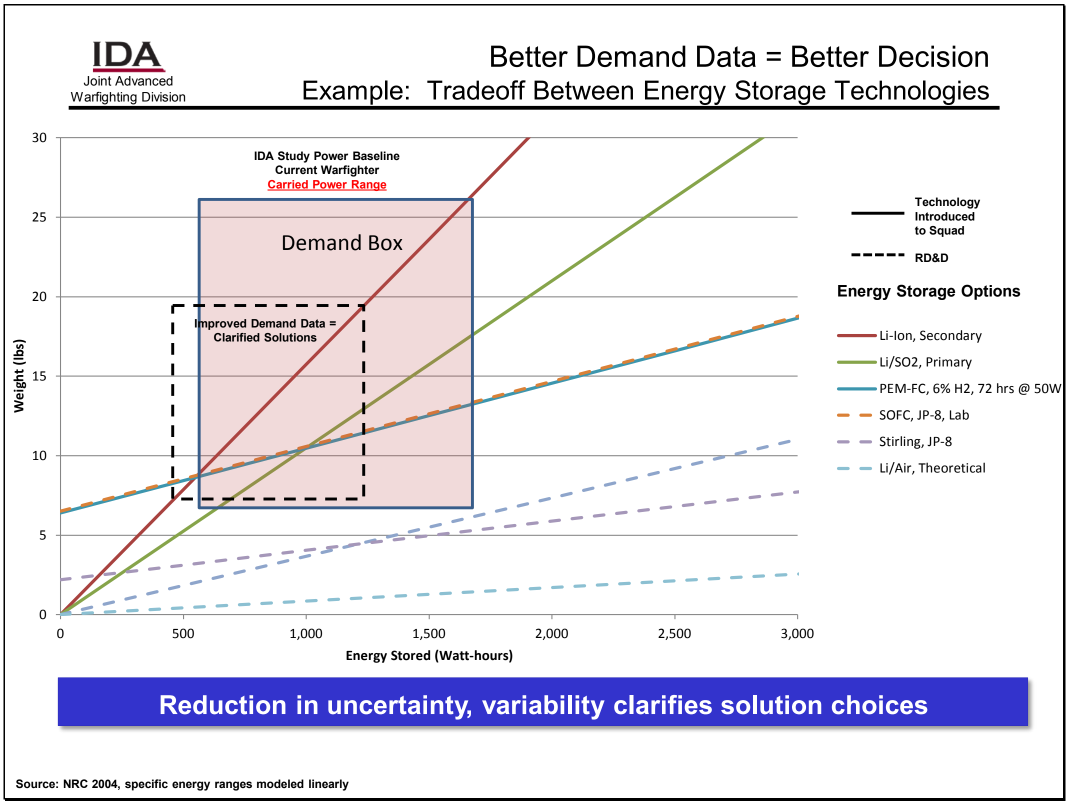
Accurate Demand Data Support Multiple Stakeholders

- Empirical data collection, augmented by "field-tested" modeling and simulation
  - Target high-impact, high-uncertainty components for data collection
  - Develop models to simulate other IBP system components
    - Establish relationships between mission, duration, warfighter role, and IBP use
- Multiple stakeholder communities could benefit from (1) higher resolution data and (2) the resulting reduced unknowns in warfighter power budgets
  - Strategic planning: higher resolution, increased accuracy in tradeoff analysis across supply-side (batteries, generation), demand-side (energy efficiency), energy management, non-materiel initiatives
  - Requirements developers: leverage data to establish performance-based demand reduction requirements
  - Technology developers: enable context-specific technology solutions
  - Warfighters: enable informed decisions on management, best uses, limits of energy resources available

Slide 37



This graph uses performance data and focuses on energy storage options:

- The greater the uncertainty on demand, the wider the demand box.
- The wider the box, the more likely some solutions will be obscured.
- At some demand levels, one storage option is superior to another, but then that relationship reverses at a higher demand level.

In short, reduced clarity in the problem space equals reduced clarity in the solution space.

SOURCE

National Research Council Committee on Soldier Power and Energy Systems, *Meeting the Energy Needs of Future Warriors*, Washington, DC: National Academies Press, 2004.

Slide 39. Recommendations

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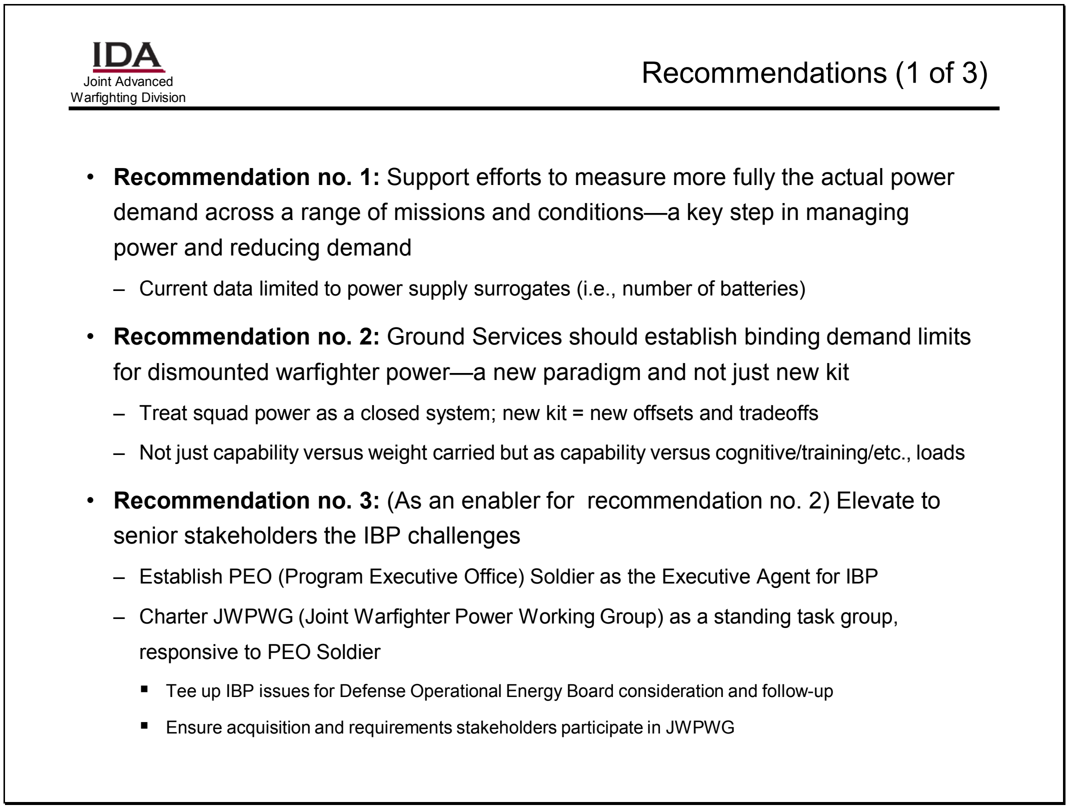
Recommendations

Slide 40



MEASURING DEMAND: The challenge of power supply and demand is only vaguely understood today, given the lack of actual demand data. The current surrogate data used in DoD are the battery loads carried (i.e., power supply). That data are certainly helpful but not nearly so much as data on how much power the various systems are consuming in an operational environment. A 2009 Army survey of non-rechargeable batteries returned from Afghanistan and Iraq found the average battery was disposed of with 42% of its original charge still remaining. (U.S. Army, Communications Electronics Command, Power Sources Branch, U.S. Army, *State of Charge Indicator Study Report*, 29 June 2009, p. 1-5.) This would at least indicate that a significant amount of that power carried on patrols is not being used, thus making estimates based on batteries carried substantially overstated.

Another factor will make batteries carried data even less useful in the future. The Army and Marine Corps field power management systems both allow (1) power to be moved between battery types and (2) the collection of additional power while on patrol (e.g., solar panels). Subsequently, the initial battery load will reveal even less about the actual total power consumed and which devices are consuming that power. Understanding which IBP solutions offer the greatest benefits is greatly hampered by the lack of this data. *Closing this data gap should be a high priority.*

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DEMAND LIMITS: In the past, aggregate demand limits were not in place for dismounted warfighters. Given the other demands for added capabilities on the warfighter, many of which demanded power, the total demand for power on warfighters increased over the last decade. But that increase in demand has been met with an increase in battery weight, along with a proliferation of battery types, which in turn has hampered mobility, complicated resupply, increased battery costs, and increased the cognitive burden ("executive functioning such as problem solving, task prioritization, assessing, etc.") on warfighters who have to manage the complex array of battery types and power-consuming devices. A systems engineering approach should be used that treats the *warfighter as a closed system with weight limits*. Those weight limits would force tradeoffs within the area of power supply: as one pound was added for some new capability, another pound would have to be removed somewhere else from the warfighter. Absent this sort of constraint, the growth in power-related weight is unlikely to stop, and the tradeoffs that have been made in the past where warfighter mobility was hindered will continue.

See the next slide for comments and a graphic on recommendation no. 3 ("Elevate to senior stakeholders the IBP challenges").

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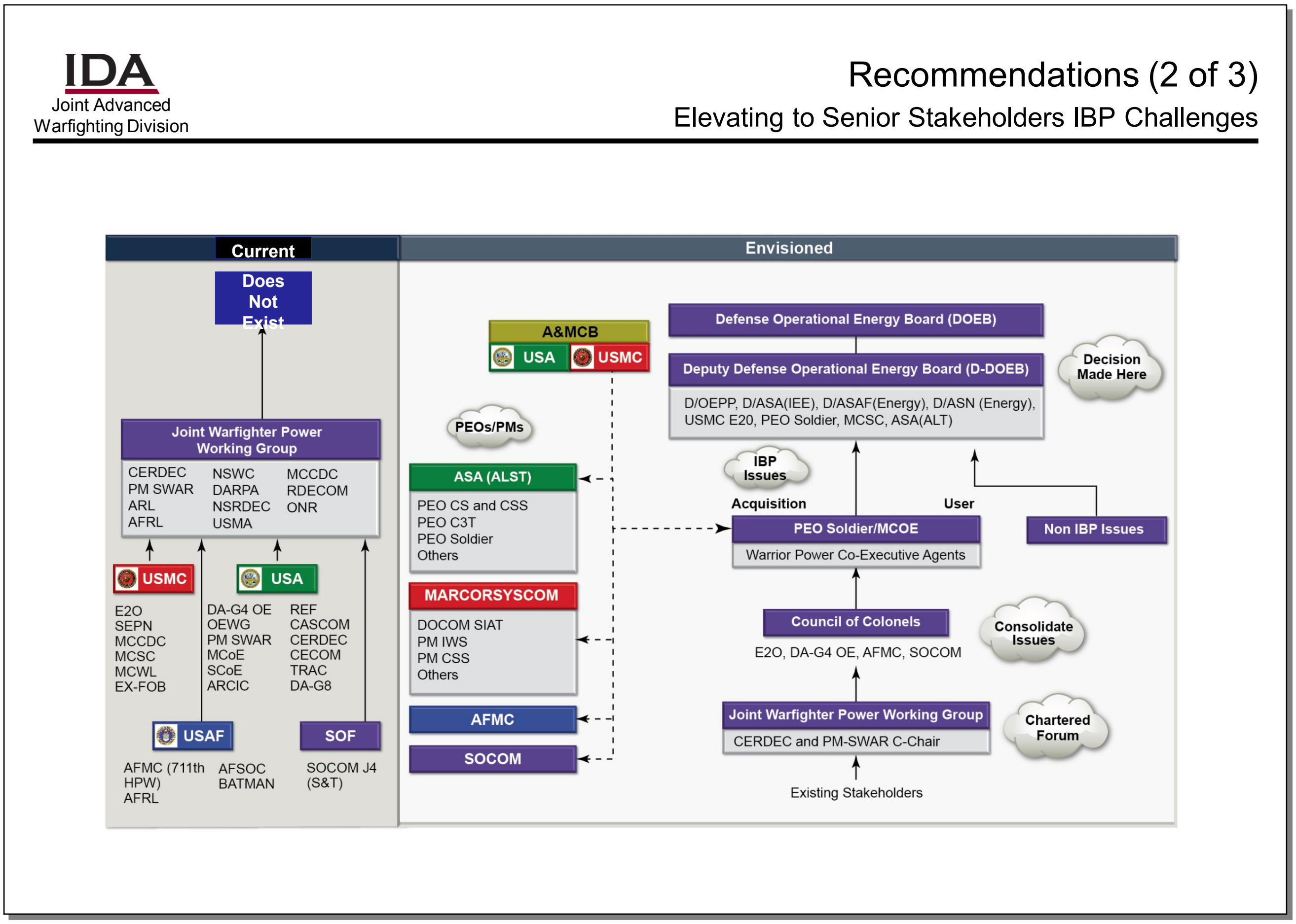

Revised Decision-Making Process: In support of recommendation no. 2, the decision-making process for IBP should be revised. The left side of the slide depicts a current structure for vetting IBP-related issues across multiple stakeholders. Warfighter equipment is procured somewhat independently and squad requirements are not fully integrated as system-level challenges. Grass-roots or bottom-up efforts to address these challenges via entities such as the Joint Warfighter Power Working Group (JWPWG) bring key stakeholders together but without the adequate oversight and support needed to drive necessary change.

The right side of the slide depicts an envisioned approach through which the JWPWG might engage senior leaderships. In the envisioned approach, the JWPWG elevates key IBP issues for consideration by a Council of Colonels drawn from IBP stakeholder organizations. Some issues may then be down-selected for consideration by flag-level decision makers at MCoE and Program Executive Office Soldier (PEO Soldier) who together constitute the DoD Executive Agents for IBP.

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Some actions by the Executive Agent for IBP may be socialized with the DoD Operational Energy Board (DOEB) to further promote cross-leveling of issues across the joint enterprise. Key actions to facilitate the envisioned approach include the following:

- Establish JWPWG as a standing task group in the DOEB.
- Include PEO Soldier, Marine Corps Systems Command (MCSC) and Assistant Secretary of the Army for Acquisition, Logistics and Technology) (ASA(AL&T)) R&T as participant reps in future Deputy DOEBs.
- Establish an existing Charter and Council of Colonels (i.e., USMC = E2O, USA = DA-G4 OE, USAF = AFMC, SOF = SOCOM J4).
- Schedule bi-annual JWPWGs in line with scheduled bi-annual D-DOEBS (45 days prior to coordinate issues and recommendations through PEO Soldier).
- Reestablish the Army/Marine Corps Board (AMCB) for “Warfighting Issues” with the Deputy Assistant Secretary of the Army (ASA) for Installations, Energy and Environment (IE&E) as chair, with “Warrior Power” as a subset. A forum will serve to hold Services accountable for efficiencies and spending initiatives.
- Create the opportunity to reduce/eliminate duplicative Service specific R&D efforts during period of significant budget constraints.
- Use the existing opportunity to firm up language for Warfighter/Soldier power Key Performance Parameters for Soldier worn-/carried-consuming devices.
- Take into account products that increase power efficiency demands before making such products “Programs of Record.” (ASA (AL&T) and Marine Corps Systems Command (MARCORSYSCOM) materiel development entities (separate PEO, power management (PM), program director (PD) directorates) are the ones who make these product decisions).

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Recommendations (3 of 3)

- Continue support to Natick Consortium, consider including
  - Deconstruct components of cognitive load, training load, etc.—seek mitigations
  - Define and validate performance and effectiveness metrics
  - Establish an IBP Warfighter Council of E-8s/E-9s…collaborate early and often
- Fund innovations in resupply modes/methods/techniques as a way to mitigate the 72-hour dismounted challenge
  - Consider coupling with fuels delivery and fuel cell technology
- Continue Service efforts orienting on power inter-operability
  - Commendable Service efforts to date in this area
  - Connector standardization and power management are keys
  - Conduct comparative field exercises with Army and USMC power management systems to better understand relative strengths
- Encourage continued outreach to interagency, allies, partners

NATICK CONSORTIUM: This promising venue for addressing IBP challenges should be supported. The consortium will bring together a diverse set of organizations and individuals that will offer the many perspectives needed to address the complex challenges of IBP. Modeling and simulation also offer a potentially rich source of insights into possible IBP solutions. The Consortium could look to the Squad Electric Power Network effort at the Naval Surface Warfare Center (Dahlgren, Virginia) for some pioneering efforts in this area.

RESUPPLY: The IDA research team found considerable possible impact from power resupply technologies but only modest efforts were underway across DoD to explore its potential. The current paradigm is 72 hours without power resupply, but a common refrain in many of the sources reviewed for this IDA project was that water, food, and ammunition might well need to be resupplied during that 72-hour window. Greater consideration should be given to power resupply options that meet the needs of dismounted patrols (e.g., stealthy, rapid response; accurate and safe for both the supplies and receiving personnel). Reliable power resupply could not only greatly ease the current constraints on power supply and demand, it could also enable missions well beyond the current 72-hour paradigm.

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POWER INTEROPERABILITY: The Services are making substantial progress in the area of power interoperability. The power management systems under development are an important part of this, allowing power in one battery type to be moved to another while also devising some standards on connections. The current Service power management development efforts would benefit from a comparison in field exercises, to better understand the relative strengths and interoperability of each Service's power management system.

CONTINUED OUTREACH: As the challenges of IBP are addressed, DoD should continue outreach to other U.S. Government agencies, allies, and partners. Many of these other organizations have similar dismounted power supply and demand challenges and they may be a source of innovated solutions not currently in the DoD portfolio. A sharing of technologies or concepts could benefit DoD not only directly but also indirectly if these potential future partners in operations were made more capable in the field.

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SOCOM Research and Development Acquisition Center

U.S. Air Force

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Program Manager Mobile Electric Power
U.S. Military Academy Operational Energy

U.S. Marine Corps

Expeditionary Energy Office
Program Manager Marine Expeditionary Rifle Squad

Marine Corps Warfighting Lab

U.S. Navy

Naval Surface Warfare Center Squad Electric Power Network
Office of Naval Research, Naval Research Lab

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Appendix B. Abbreviations

ACOG	Advanced Combat Optical Gunsight
AFMC	Air Force Materiel Command
AFRL	Air Force Research Laboratory
AFSOC	Air Force Special Operations Command
AMCB	Army & Marine Corps Board
AR	Army Reserve
ARCIC	Army Capabilities Integration Center
ARL	Army Research Laboratory
ASA(AL&T)	Assistant Secretary of the Army (Acquisition, Logistics and Technology)
ASA (IE&E)	Assistant Secretary of the Army (Installations, Energy and Environment)
ASD	Assistant Secretary of Defense
BAT-NET	Battery Manufacturing Technologies
BATMAN	Battlefield Air Targeting, Man-Aided kNowledge (Air Force)
CASCOM	Combined Arms Support Command
CBO	Congressional Budget Office
CECOM	U.S. Army Communications – Electronic Command
CERDEC	U.S. Army Communications – Electronics Research, Development and Engineering Center
C-IED	counter-improvised explosive device
DA-G4 OE	Department of the Army G4 Operational Energy Office
DARPA	Defense Advanced Research Projects Agency
D-DOEB	Deputy Defense Operational Energy Board
DOD	Department of Defense
DOEB	Defense Operational Energy Board
DOTMLPF	doctrine, organization, training, materiel, leadership and education, personnel, and facilities
E2O	Expeditionary Energy Office (USMC)
Ex-FOB	Experimental Forward Operating Base (USMC)
FY	fiscal year
GPS	global positioning system
GSS	Ground Soldier System

HIDES	Homeland Security, Biometric Identification, and Personal Detection Ethics
hr	hour
IBP	Individual Battlefield Power
IDA	Institute for Defense Analyses
IED	improvised explosive device
IPB	Individual Battlefield Power
IR	infrared
JAWD	Joint Advanced Warfighting Division
JWPWG	Joint Warfighter Power Working Group
k, K	thousand
km	kilometer
kph	kilometer per hour
lbs.	pounds
MCCDC	Marine Corps Combat Development Center
MCoE	Maneuver Center of Excellence
MCSC	Marine Corps Systems Command
MCWL	Marine Corps Warfighting Laboratory
MED	medical
Mgr	manager
MOE	measure of effectiveness
MOP	measure of performance
NATICK	US Army Natick Soldier Research, Development and Engineering Center
NSRDEC	Natick Soldier Research, Development and Engineering Center
NSWC	Naval Surface Warfare Center
NW	Nett Warrior
OE	operational energy
OEPP	Operational Energy Plans and Programs
OEWG	Operational Energy Working Group
ONR	Office of Naval Research
PD	program director
PEO	Program Executive Office
PEO C3T	Program Executive Office for Command, Control, Communications, and Tactical
PEO CS&CSS	Program Executive Office Combat Support & Combat Service Support
PEO Soldier	Program Executive Office Soldier
PL	platoon
PLI	position location information

PM	power management
PM-SWAR	Program Manager – Soldier Warrior
QTY	quantity
R&D	research and development
RCIED	radio-controlled improvised explosive device
RCO	regional contracting office
RD&D	research design and development
RDECOM	U.S. Army Research, Development and Engineering Command
ROTC	Reserve Officer Training Corps
RR	Rifleman Radio
RTO	rear tactical operations
S&T	science and technology
SBCT	Stryker brigade combat team
SCoE	Sustainment Center of Excellence
SEPN	Squad Electric Power Network
SINCGAR1S	Single Channel Ground and Airborne Radio System
SOCOM	Special Operations Command
SOF	Special Operations Force
SUP	Small Unit Power
TL	team leader
TRADOC	Training and Doctrine Command
UAV	unmanned aerial vehicle
USA	United States Army
USAF	United States Air Force
USMA	United States Military Academy
USMC	United States Marine Corps
VA	Veterans Administration
W/hrs, Wh	watts-hour
WWI	World War I (One)
WWII	World War II (Two)

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14. ABSTRACT

New capabilities have increased the demand and weight of individual battlefield power (IBP) in both the individual warfighters and the small units at the squad level. The warfighters now carry increasingly burdensome power sources and/or operate at less time with the full services of their electrically powered enablers. A number of DOD programs seek to counter this by providing more efficient and interoperable gear with lighter and less bulky power sources. This annotated briefing identifies the most significant challenges and enablers over the next five years to the power budget of the individual and the squad-level joint warfighter. The briefing also recognizes Service requirements, objectives, and metrics; key materiel and non-materiel initiatives; and energy-related capability trade-offs. It addresses trends in warfighter loads and squad power requirements, all of which are currently unsustainable. Finally, the team's recommendations focus on relative importance of requirements, energy technologies, non-materiel approaches, system interoperability priorities, and metrics to help prioritize tradeoffs.

15. SUBJECT TERMS

Afghanistan; batteries, clothing, and equipment; counter-improvised explosive device (C-IED); demand- and supply-side variables; dismount; energy storage, supply, and demand; individual battlefield power (IBP); infantry; metrics; mission; musculoskeletal injuries; Nett Warrior; operational energy (OE); power budget; resupply; and warfighter power.

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